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EFFECTS OF JP-4 FUEL ON GRAPHITE/EPOXY COMPOSITES

B. L. White
Structural Concepts Branch
Structures and Dynamics Division

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The primary objective of this program was to determine if structural properties of graphite/epoxy composite laminates could be degraded by subjecting the material to JP-4 fuel under pressure for an extended period of time. The investigation consisted of three extended evaluations in which a total of 305 specimens were tested in various modes. The study dealt primarily with tensile testing of fuel and ambient environment exposed laminates and oven dried laminates to determine relative strength values. The data shows little to no

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degradation of the Hercules AS 3501-5A graphite/epoxy material propertics after being exposed to JP-4 fuel at a 40 psi pressure for six months.

FOREWORD

This report describes an in-house investigation conducted by the Structural Concepts Branch (FIBC), Structures and Dynamics Division, Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 2401, "Structural Mechanics", Task 240103, "Advanced Structures for Military Aerospace Vehicles", Work Unit 24010338, "Preliminary Design of Aircraft Structures." Mr. Billy L. White, AFWAL/FIBCA, served as Project Engineer and test fixture designer; Mr. Robert T. Achard, AFWAL/FIBCC, supervised the fabrication of the composite specimens; and Mr. Harold D. Stalnaker, AFWAL/FIBE, was the Test Engineer.

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SECTION I

INTRODUCTION

During the past decade, composite materials have developed into current state-of-the-art materials commanding an increasing percentage of the structural materials used in high performance aircraft. Aircraft are now being flown, such as the F-18 and AV8B, that contain composite materials in primary structure throughout the aircraft. These materials are subject to numerous environmental effects including prolonged contact with liquids such as jet fuel.

It is well known that the epoxies used as a matrix in fibrous composite structures absorb moisture. This moisture causes a reduction in certain structural properties of the matrix. Questions still arise as to the possible degradation of composite structural properties due to jet fuel penetration into the epoxy matrix. The resistance of the composites to JP-4 fuel depends largely on the chemical resistance of the resin, and on the presence of defects such as cracks, voids, resin-rich regions and "dry" regions. Such defects can arise during the fabrication process or from subsequent service usage.

In the past, several investigations have been conducted where the composite materials were simply subjected to immersion into fuels to determine if any deterioration could be detected. In all cases except for a few test points, the data has shown little or no degradation in material properties due to contact with fuels (References 1 through 4).

SECTION II

OBJECTIVES

The primary objective of this program was to determine if structural properties of graphite-epoxy composite laminates could be degraded by subjecting the material to JP-4 fuel under pressure for an extended period of time. Also, an investigation was conducted to determine if fuel tank sump water would deteriorate the laminate material properties. A secondary aim was to observe whether the laminates exposed to pressurized fuel would absorb enough fuel for a measurable weight gain.

SECTION III

SCOPE

Tests have been conducted previously in which composites were simply immersed in JP-4 for long periods of time. No degradation in material properties was found as a result of these tests. Unlike this approach, the specimens in this program had pressure applied to one face of the laminate, tending to force the fuel into the laminate. To subject the test specimens to pressurized fuel required the design, analysis, and fabrication of an innovative test fixture. This fixture allowed the composite panels to act as fuel tank walls without being over-stressed in bending when high fuel tank pressures were applied for long periods of time. (Figure 1)

The investigation consisted of three extended evaluations in which a total of 305 specimens were tested in various modes. During the initial phase, three laminate panels were fabricated using Hercules AS 3501-5A graphite/epoxy material system with a stacking sequence of $[0_2/90_2/\pm 45]_s$. Two of the panels were installed in the fuel tank test fixture and the third one was used as a control specimen for baseline data. The fuel tank specimens were subjected to 20 psi pressure for six weeks. In the second test phase, four panels were fabricated from the same material systems as the first test but had 16 plies with orientation of $(\pm 45^{o})_{4s}$. Two of the panels were placed in the test fixture for six months under a fuel pressure of 40 psi. One panel was placed next to the test fixture for ambient environment exposure and one panel was placed in an oven at 140^{o}F as a control specimen. The third phase test was essentially the same as the second phase except a mixture of JP-4 fuel and 3% artificial fuel tank sump water was placed in the test fixture to determine sump water effects on material properties.

Following the extended test period in each test phase, the laminate panels were removed from their respective test areas and were cut into 20 tensile test specimens of 1 inch width and 10 inches length. Additionally, three of the tensile test specimens from each panel were used for preparing specimens for flexural strength and short beam shear tests.

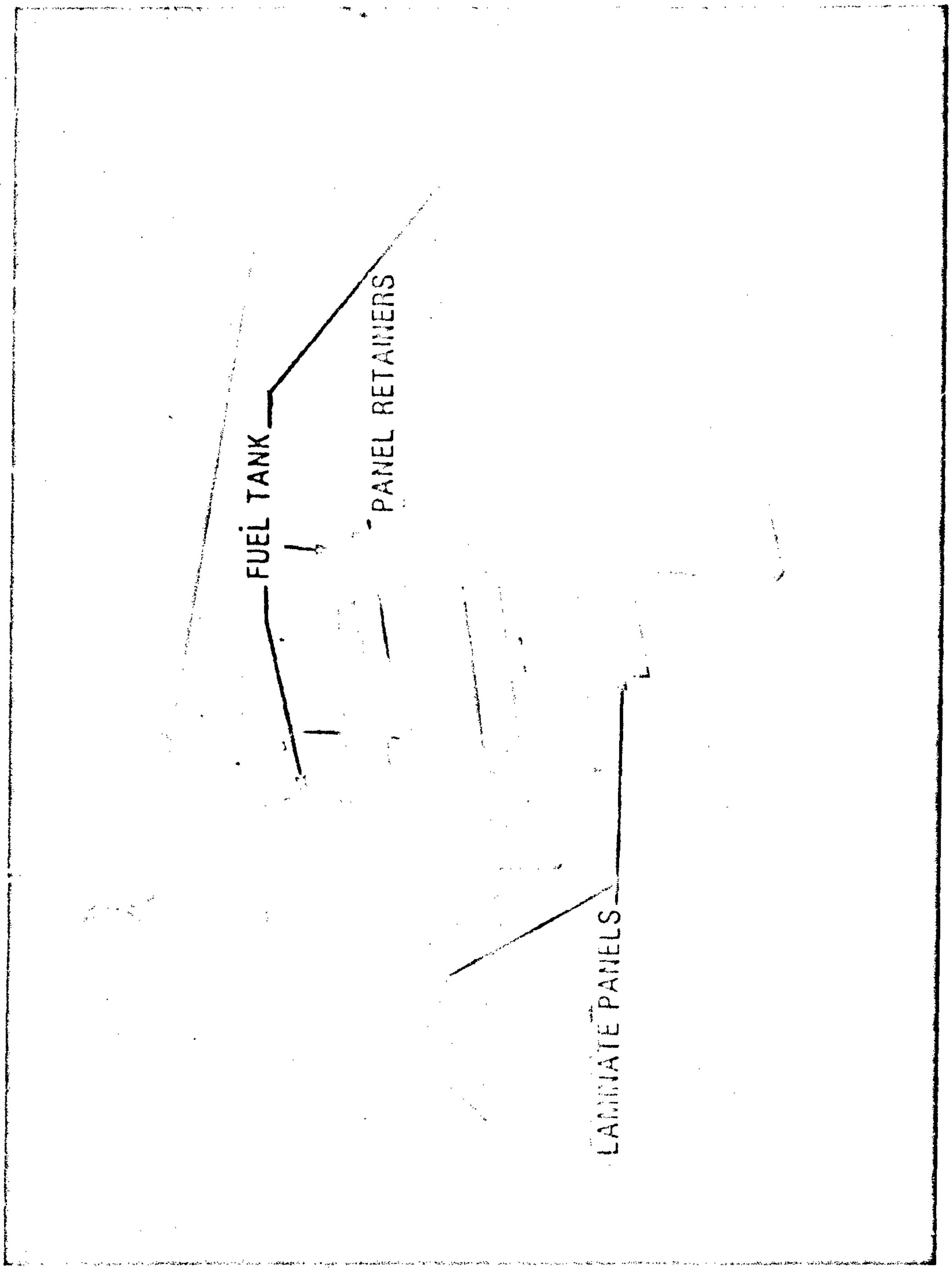

Figure 1. Test Fixture Components

SECTION IV

TEST FIXTURE

To accomplish the objective of the program, an innovative fuel tank test fixture had to be designed, analyzed, and built so that large composite laminate panels could be subjected to pressurized JP-4 fuel. (Figure 2) The test fixture was designed with a center plate cut out to contain fuel. The two outside plates of the fixture were designed with cutouts permitting the composite panels to be exposed on the inside to pressurized fuel and on the outside to the atmosphere. These cutouts had posts every two inches to support a 23 x 10 inch test panel and to prevent excessive deflection while under pressure. (Figure 3)

An extensive analysis of the fuel tank design was made prior to fabrication to assure that the fuel tank fixture would n t fail due to internal pressure. The weakest area of the fixture was found to be the posts between the cutouts in the plates. The posts were analyzed for fixed end boundary conditions. AISI 4130, low carbon steel material with a tensile yield stress (F_{ty}) of 70,000 psi and an ultimate tensile stress (F_{tu}) of 90,000 psi was used in the initial analysis of the test fixture (Reference 6). The system was analyzed for a test pressure of 100 psi. For this pressure, the stresses were found to be 10,816 and the MS was 5.47. Thus, the fuel tank fixture was designed to contain pressures much higher thar the maximum 40 psi used during the programs.

The test fixture was designed to eliminate sealing problems to the extent possible. Recesses were cut into the end plates to seal the composite test panels and specimen retainers were designed to hold them securely against the tank walls. Buna-N rubber material was cut to shape and placed around the fuel tank plate boundaries to prevent leakage of the system.

A pressurization system was designed which would prevent any possibility of over-pressurization during the course of the test. The pressurization system incorporated a small cylinder with a piston that

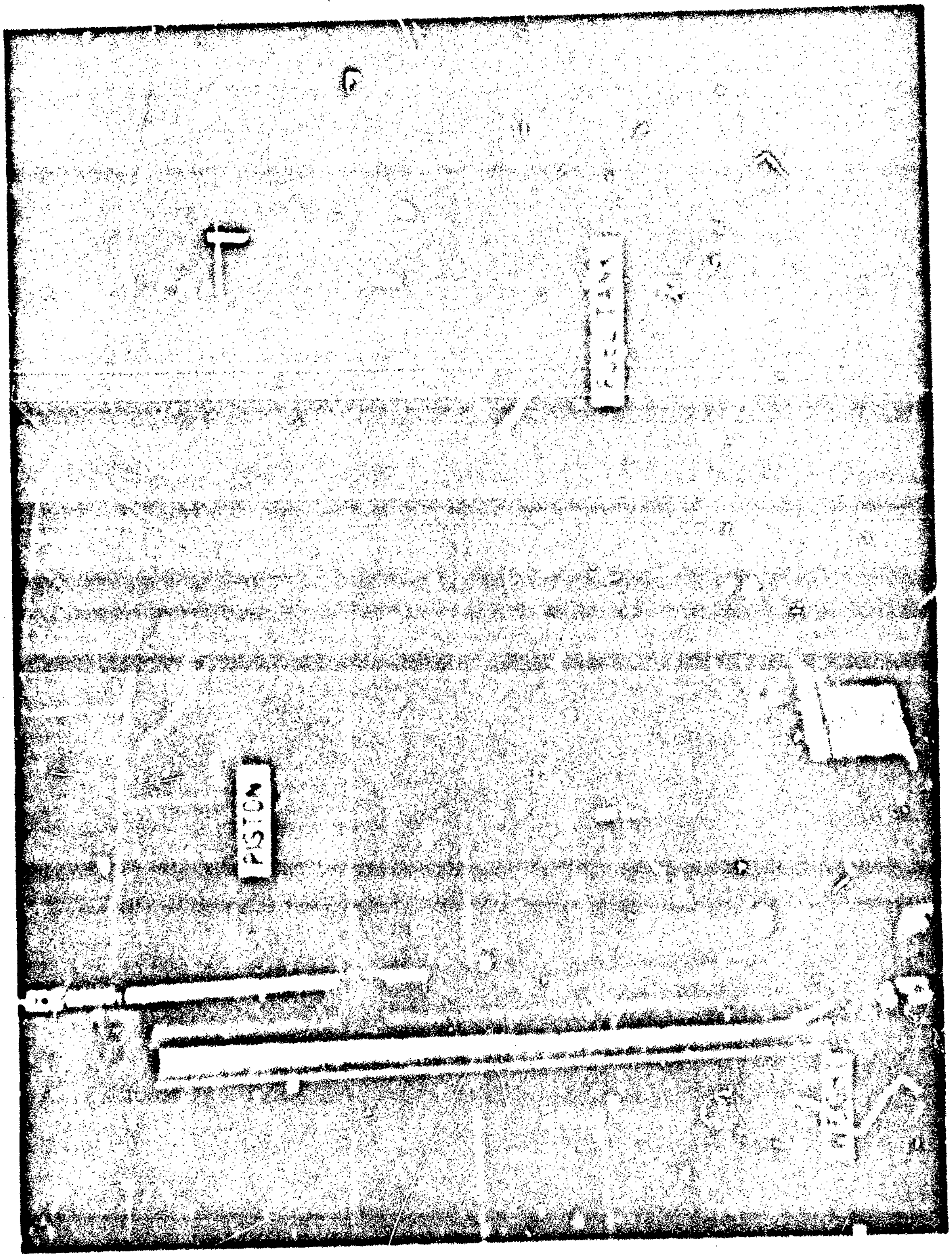

Figure 2 Test Fixture

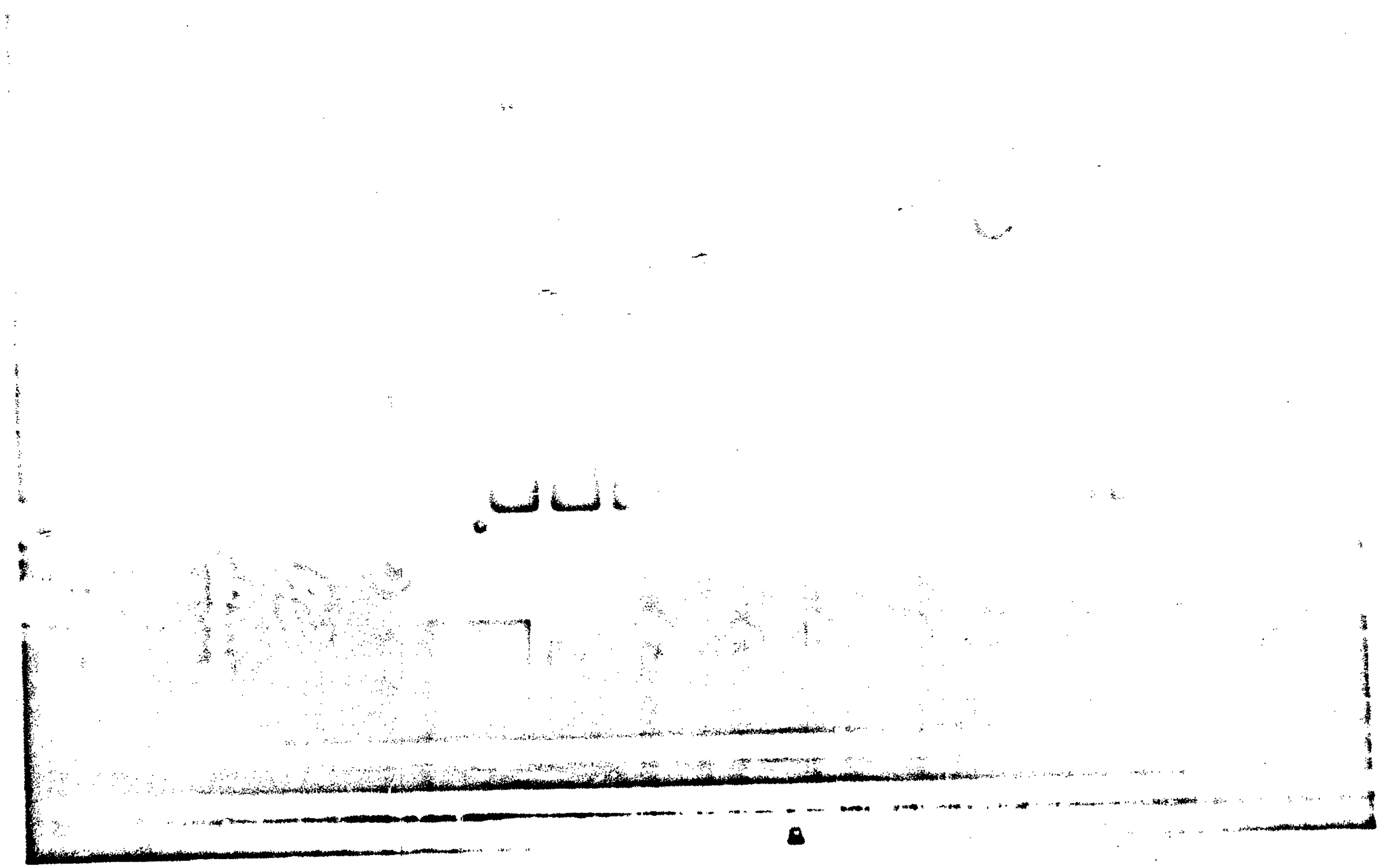

Figure 3. Test Fixture Cutout.

was connected by a shaft to dead weights as shown in Figure 2. The cylinder filled with fuel when the fuel tank was filled. The piston compressed the fuel when the dead weight was applied, thus restricting the maximum system pressure. Over-pressurization could occur only by the application of more weight. A pressure gage was installed between the cylinder and the fuel tank for monitoring the system pressure.

The possibility of fuel leaking during the long test periods was taken into consideration when the test fixture was designed and the location of the facilities was selected. The fuel tank test fixture was designed to hold only 1.37 gallons of JP-4 fuel and the pressurization system held approximately 0.1 gallons of fuel. Consequently, if a leak had occurred, very little fuel would have been present for a possible fire. The conditions necessary for combustion were not permitted. The JP-4 fuel was enclosed in a sealed pressurized system, the test building was well ventilated, and no ignition sources were present. Also, the fuel tank test fixture was grounded to prevent the possibility of static electricity buildup.

SECTION V

TEST LAMINATE SIZING

To determine the most efficient size test fixture, several different size composite test panels were analyzed with 10 different laminate schedules of 8 to 16 plies each. Problem areas encountered during the design of the composite panels included: (1) larger panels, if unsupported, would have excessive deflection, which could result in sealing problems, (2) small panels would have small deflections, but would not provide an adequate size or quantity of tensile test specimens; and (3) specimens from a panel that was very thick could not be failed in the test machine.

The analysis of several panels with different thicknesses and laminate orientations indicated that the 12 ply laminate panel with a lay-up of $[0_2/90_2/\pm 45]_s$ was the most suitable for the initial test. The results of the analysis indicated that a 20 psi test pressure would deflect the panel, supported by the test fixture cutout bars, .0037 inches at the center with a margin of safety of 8.39. This was an adequate MS to preclude possible failure due to the test pressure. The analyses of the graphite/epoxy composite panels were made utilizing two computer programs. The "Finite Element Plate Bending Analysis" program provided panel deflection data and resultant moments at the maximum deflection point (Reference 8). These resultant moments were input into the "Laminate Point Stress Analysis (SQ-5)" program which provided the margin of safety for each panel analyzed (Reference 9).

SECTION VI

TEST PROGRAM

1. TEST NO. 1

For the initial evaluation, a 12 ply composite panel with a stacking sequence of $[0_2/90_2/\pm 45]_s$ was selected to be tested at a fuel tank pressure of 20 psi for a six-week duration. Three laminate panels with dimensions of 23 x 10 inches were fabricated utilizing Hercules AS 3501-5A graphite/epoxy material. (Figure 4) The three laminates were cured in a single autoclave run and NDI was performed on each panel to determine if any voids or flaws were present. No significant defects were evident from the C-scan or X-ray inspections. The resin content was measured to be 30.5% by weight. Fiberglass ($0^{\circ}/90^{\circ}$ "S" glass) tabs were bonded to the laminate grip sections prior to insertion into the 140° drying oven. The drying oven was used to assure a minimum moisture content at the start of the test period.

Two of the test panels (1A and 1B) were removed from the oven and placed in the fuel tank test fixture with one side subjected to JP-4 fuel at a 20 psi pressure and the other side to the ambient environment. The third panel (1C) was used as a control specimen exposed to the ambient environment. This panel was mounted on a metal plate with drying desiccant placed between the composite laminate and the plate. Consequently, the outside surface was subjected to the humid atmosphere and the inside was kept dry. Therefore, one side of the test panels were all exposed to the ambient environment. As a result, any reduction found in tensile strength could be attributed to the fuel exposure. The fuel tank test fixture and the control panel were placed in a remote building for the six week test period. The humidity and temperature of the area were recorded each afternoon. The temperature recorded during the test period ranged from $24^{\circ}F$ to $76^{\circ}F$, and the humidity ranged from 49% to 100%.

The three panels were removed from the drying oven and weighed prior to the start of the test period and weighed again after removal from the test fixture at the end of the six week test period.

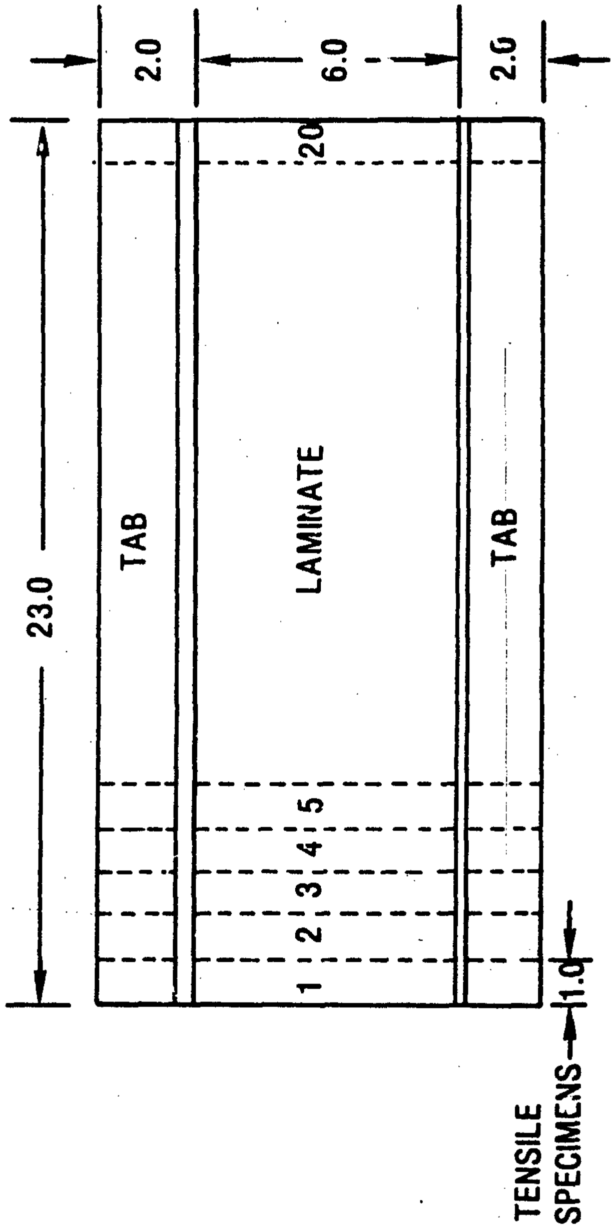

Figure 4. Composite Laminate Panels

The before and after test weights were:

Specimen No.	Weight (Grams) Before	After	Change
1A (Fuel Soaked)	777.4	777.5	0.1 (.01%)
1B (Fuel Soaked)	780.0	780.4	0.4 (.05%)
1C (Ambient Environment)	778.2	778.3	0.1 (.01%)

Further evaluation of moisture content was made since the panels were so large and the weight change so small that the accuracy of the available scales was questionable. The ends were cut off each panel and weighed. They were placed in a drying oven at 140°F for 30 days, removed and weighed. The results were:

Specimen No.	Weight (Grams) Before	After	Change
1A	10.7263	10.6995	0.0268 (0.25%)
1B	5.6273	5.6155	0.0188 (0.21%)
1C	13.6639	13.6290	0.0349 (0.26%)

The results show that all three specimens had approximately 0.25% decrease in weight. It is evident from the small weight change that the resistance of the composite epoxies to JP-4 fuel is very good.

Immediately following the removal from the test fixture and after weighing, the test panels were cut into tensile specimens (Figure 5). Great care was taken to assure that the test specimens were cut in the 0° ply direction. A diamond cutoff wheel was used to cut each panel into 20 tensile test specimens one inch wide and 10 inches long (1 x 10). Three of the tensile test specimens (Numbers 1, 10, and 19) from each panel were saved for cutting into short beam shear and flexural strength test specimens (Figures 6 and 7).

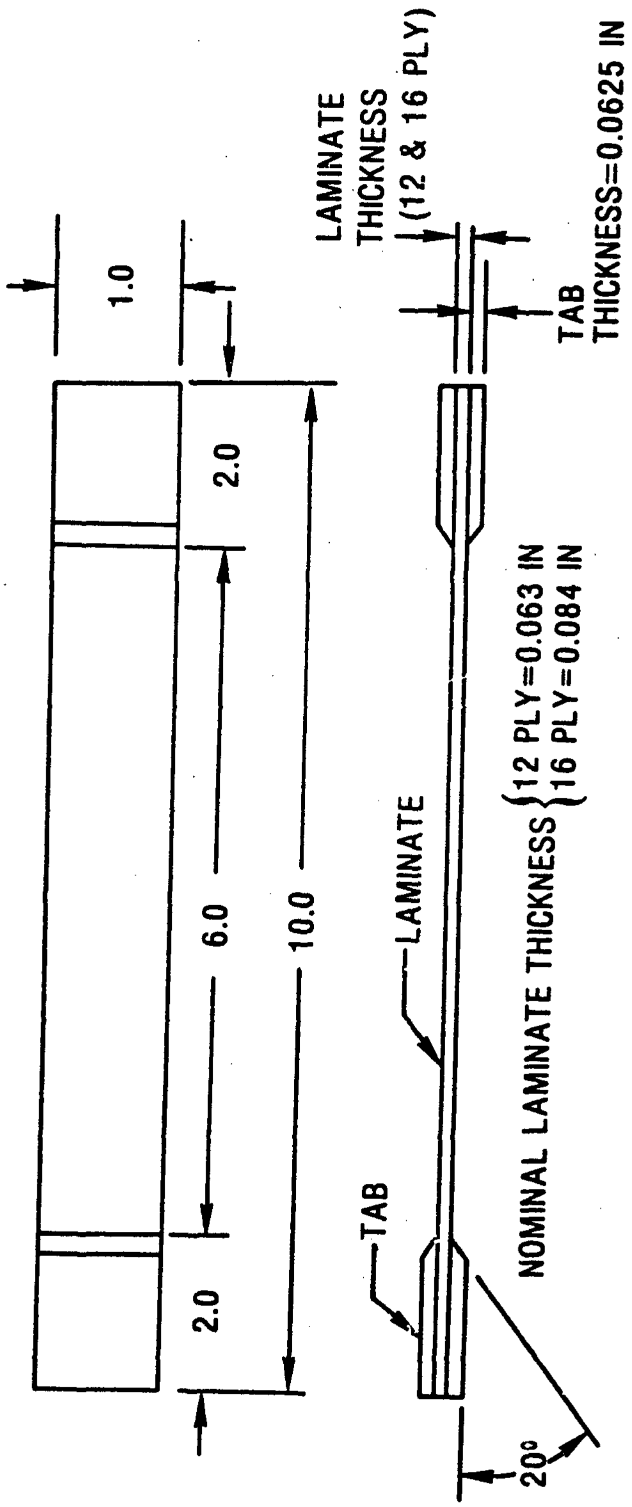

Figure 5. Tensile Test Specimen

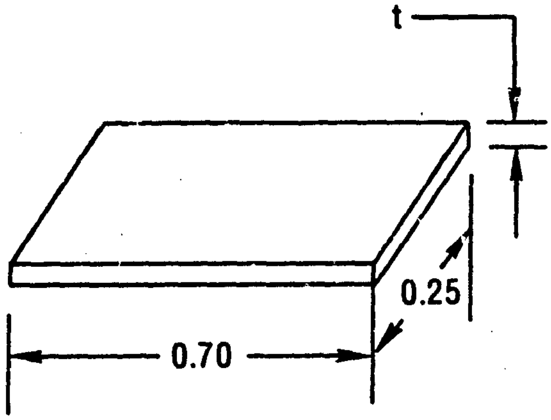

Figure 6. Short Beam Shear Test Specimen

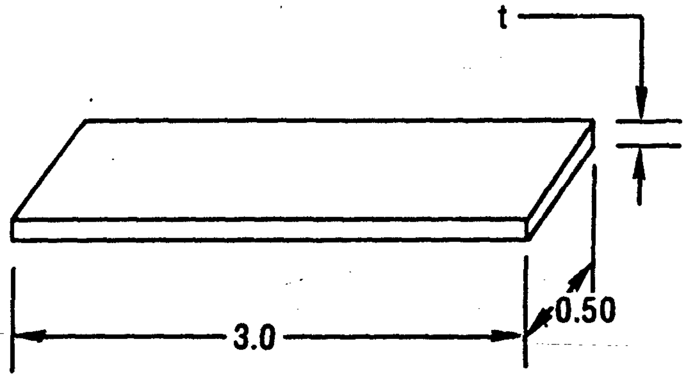

Figure 7. Flexural Strength Test Specimen

Seventeen of the tensile test specimens from each of the three panels were tested to failure at ambient temperature in an Instron test machine. The specimens were loaded at a crosshead speed of 0.05 inches per minute. The results of the tensile tests were inconclusive as to whether or not the JP-4 fuel degraded the graphite-epoxy matrix since the laminate had a fiber dominated failure. The strength at the initial failure load was calculated using a nominal area for the fiber controlled laminate of .063 in^2 (12 ply x 0.00525 in./ply). The average failure strengths were 103,238; 98,502 and 97,621 (psi) for panels 1A, 1B, and 1C respectively (Figure A-1 and Table A-1).

Interlaminar shear stresses were determined by the short beam shear (SBS) test which is used primarily as a laminate quality check method. The short beam shear test method normally uses unidirectional laminates with the fibers running parallel to the length of the specimen. Although the test laminates were not specifically tailored to the SBS tests, it was decided in this program to use them for comparison purposes only to investigate effects of fuel exposure. However, the data generated is not recommended to be used as structural allowable values. Six SBS test specimens were cut from each of the three laminates. The specimen has the dimensions of 0.250 inch wide and 0.700 inch long. The specimen configuration is shown in Figure 6.

The short beam shear test fixture untilized a 3-point load assembly. The specimen supports were adjusted to a span-to-depth according to the relationship:

$$\frac{S}{T} = 4$$

where S = span, inch

T = specimen thickness, inch

Therefore, with a specimen nominal thickness of .063 inch, a span of .25 inch was used between the specimen supports. The tests were conducted with the Instron test machine crosshead speed of 0.05 inch per

minute. The short beam shear strength at failure was calculated according to the following equation:

$$\tau = \frac{3P}{4A}$$

where τ = Short beam shear strength, psi

P = Total load at failure, lbs

A = Cross sectional area, in^2

The average shear strength of the two fuel soaked laminates, 1A and 1B, were 11,286 and 10,971 psi respectively and the control (ambient environment) laminate, 1C, was 11,425 psi (Figure A-2 and Table A-2).

Six flexural test specimens were prepared from each of the three panels 1A, 1B, and 1C. Flexural testing was performed principally for checking the laminate material quality rather than for establishing basic mechanical properties. This is a convenient method for checking laminate quality since it simultaneously applies tension, compression, and horizontal shear. The test specimen was a straight sided, rectangular cross section beam 3.0 inches long and 0.5 inch in width. The specimen configuration is shown in Figure 7.

Flexural testing was conducted using a four-point loading method with the specimen support span of 2.0 inches. Each specimen was loaded to failure in an Instron test machine at a crosshead speed of 0.05 inch per minute. The ultimate flexural strength was calculated by the following equation:

$$\sigma = \frac{3PL}{4bt^2}$$

where: τ = stress in outer fiber at failure, psi

P = maximum load carried by the specimen, lbs

L = major span, inch

b = width of specimen, inch

t = thickness of specimen, inch

Comparison of the flexural strengths of the three panels shows very little difference in the values. The ambient environment exposed specimen, 1C, flexural strengths average value was 165,438 psi. The two fuel-soaked specimen strengths were 166,730 psi (1A) and 164,441 psi (1B) (Figure A-3 and Table A-3).

2. TEST NO. 2

It was evident from the first test phase that the failure of the specimen was fiber controlled and the effects of JP-4 fuel on the matrix could not be determined with any reliability. It was decided that the next test should utilize a $\pm 45^0$ laminate schedule so the failure would be matrix rather than fiber controlled.

For the second test phase, the fuel tank pressure was increased to 40 psi and the test duration increased to six months in an attempt to force the fuel through the composite matrix. Analysis of a $\pm 45^0$ stacking sequence indicated that a 16 ply laminate would be required to prevent excessive deflection when exposed to the 40 psi test pressure. Also, four panel specimens were fabricated utilizing Hercules AS 3501-5A graphite-epoxy material rather than three used during the first test. The extra panel was used as a control panel and was placed in a 140^0F drying oven for the duration of the test. The four panels were cured in a single autoclave run and NDI was performed on each panel to determine if any voids or flaws were present. No defects were evident from the C-scan and X-ray inspections. The resin content was measured to be 31% by weight. Fiberglass tabs were bonded to the grip sections prior to inserting the four panels in the 140^0F drying oven. The drying oven was used to assure a minimum moisture content at the start of the test period.

Two of the test panels (2A and 2B) were removed from the oven and placed in the fuel tank test fixture with inside subjected to JP-4 fuel at a 40 psi pressure and the outside to the atmosphere. The third panel (2C) was used as a control specimen exposed to the ambient environment. This panel was mounted on a metal plate with drying desiccant placed

between the composite laminate and the plate. This resulted in the outside surface being subjected to the atmosphere and the inside surface staying dry. The fourth panel (2D) remained in the 140°F drying oven for the six month test period. The outside air temperature at the test site ranged from 51°F to 92°F and the humidity ranged from 39% to 100% during the test period.

The four panels were removed from the drying oven and weighed prior to start of the test period. They were once again weighed after the six month test period. The before and after test weights were:

Specimen No.	Weight (Grams) Before	After	Change
2A (Fuel Soaked)	901.1	902.9	+1.8 (.20%)
2B (Fuel Soaked)	895.6	897.0	+1.4 (.16%)
2C (Ambient Environment)	901.9	902.0	+0.1 (.01%)
2D (Oven Control)	898.3	897.6	-0.7 (-.08%)

The weight change data is questionable since it is improbable that the available scales could accurately measure the small change in the panel weights. It does indicate that the composite matrix never absorbed an exorbitant quantity of fuel.

The four test panels were each cut into 20 tensile test specimens of one inch width and ten inches in length. As in the first test, great care was taken to assure that the specimens were cut in the 0° direction. Three of the cut specimens from each panel (numbers 2, 10, and 18) were saved for use as flexural strength and short beam shear test specimens (Figures 6 and 7).

Sixty-eight tensile test specimens, 17 from each panel, were tested to failure at ambient temperature in an Instron test machine. Prior to testing, each specimen was measured for thickness and width in three places for determining specimen area. The failure stress of each

specimen was calculated using the average area and failure load. A mean stress, standard deviation, and coefficient of variation were calculated for the 17 specimens. The standard deviation for all data sets was less than one percent of the mean stress except the oven control panel, which was 1.17 percent. The mean failure strengths from the four panels shows a very small difference in value. The oven-dried control panel specimen strengths were slightly higher than the fuel-soaked and ambient-environment exposed panel specimens, which were essentially the same. The mean failure strength for the oven control panel specimens was 27,421 psi. The failure strength for the two fuel-exposed panel specimens and the exposed ambient environment panel specimens were 26,964 psi, 26,944 psi, and 26,982 psi respectively (Figure A-1 and Table A-4).

Interlaminar shear stresses were determined by the short beam shear (SBS) test as was described in Test No. 1. This test utilized specimen numbers 2, 10, and 18 of each panel for preparing SBS specimens (Figure 6). Three SBS coupons were cut from each specimen. The SBS test used a 3-point load assembly with supports adjusted to a span-to-depth ratio of four. A span of approximately 0.35 inch between the specimen supports was used for the 16 ply SBS specimen, which had a nominal thickness of 0.084 inch.

The results of the short beam shear tests, in which nine specimens from each panel were tested to failure, show that the ambient environment exposed panel (2C) had the greatest shear strength, whereas, the two fuel soaked panels (2A and 2B) had essentially the same shear strength as the oven control panel (2D). The mean shear strengths of the two fuel exposed panel specimens were 11,867 and 11,558 psi; the oven control panel had a strength of 11,868 psi and the ambient environment exposed panel shear strength was 12,415 psi (Figure A-2 and Table A-5).

The flexural test specimens were prepared from specimen numbers 2, 10, and 18 from each of the four panels (2A, 2B, 2C, and 2D) (Figure 7). The testing and flexural strength calculations were performed as in Test No. 1. The fuel-exposed specimens had average flexural strengths of

45,161 psi and 44,834 psi and the ambient-environment-exposed and oven dried specimens average flexural strengths were 46,432 psi and 46,140 psi respectively (Figure 10 and Table 6).

3. TEST NO. 3

The third test phase consisted of the same type material, Hercules AS 3501-5A, and laminate schedule, $\pm 45^{o}$, as Test No. 2 with some variations in procedures. Since very little change was evident in Test No. 2 of the fuel-soaked and ambient-environment-exposed panels, it was decided to (1) determine the effects of sump water on the graphite-epoxy material; (2) instrument some of the tensile test specimens; (3) perform only tensile tests; and (4) fabricate two extra panels and test them prior to the start of the fuel soak tests.

For the third test, a 16 ply composite laminate with a stacking sequence of $(\pm 45^{o})_{4S}$ was selected to be evaluated at a fuel tank pressure of 40 psi for a six month duration. Also, six panels were fabricated rather than the four used during the second test. The two extra panels were dried in an oven for four weeks at $140^{o}F$ and tensile tested prior to the start of the fuel soak test to determine if the tensile properties had a significant change during the test period. The six panels were cured in a single autoclave run and NDI was performed on each panel to determine if any voids or flaws were present. No significant defects were evident from the C-scan and X-ray inspections. The resin content was measured to be 28.8% by weight. The panels were placed in a $140^{o}F$ drying oven to assure a minimum moisture content at the start of the test period.

Two test panels (3A and 3B) were removed from the oven, weighed, and placed in a fuel tank test fixture. The third panel (3C) was used as a control specimen exposed to the ambient environment. The fourth panel (4D) remained in the drying oven for the six month test period. The fifth and sixth panels (4E and 4F) were cut into 20 tensile test specimens each. The tensile test specimens, numbers 2, 10, and 18 were instrumented on both sides with high elongation strain gages. Tensile tests were conducted on the 40 test specimens.

The fuel tank test fixture was filled with JP-4 fuel and 5% sump water. The artificial sump water was prepared by General Dynamics, Fort Worth Division, from the formula given in the Materials Laboratory Technical Report entitled, "Elastomers for Fuel Systems Containing Micro-Organisms-Controlling Additives". (Reference 7 and Table A-3). The artificial fuel tank sump water would not readily blend with the JP-4 fuel. The solution had to be mixed in a sonic vibrator. The 5% solution of sump water and JP-4 fuel was placed in the test fixture and tank was pressurized to 40 psi for the six month test period. The outside air temperature of the test site ranged from 46°F to 87°F and the humidity ranged from 43% to 92% during the test period.

The four panels were removed from their test area after six months and weighed. The before and after test weights were:

Specimen No.	Weight (Grams) Before	After	Change
3A (Fuel Soaked)	853.7	855.6	2.1 (0.[illegible]%)
3B (Fuel Soaked)	850.4	852.4	2.0 (0.24%)
3C (Ambient Environment)	852.5	854.1	1.6 (0.1[illegible]%)
3D (Oven Control)	851.4	851.1	-0.3 (0.0[illegible]%)

The weight change data is questionable since it is improbable that the available scales could accurately measure the small change in the panel weights. It does indicate that the composite matrix never absorbed an exorbitant quantity of fuel.

A total of 120 tensile specimens were tested to failure in Test No. 3. Twenty specimens were prepared from each panel. Three test specimens from each panel were instrumented with strain gages and the data plotted in Figure A-4. A mean stress, standard deviation, and coefficient of variation were calculated for each set of data. The standard deviation for all data sets was less than two precent of the mean stress with the oven control data having the largest coefficient of variation, which was 1.76. The results show that the fuel-sump water

exposed specimens mean strengths had a decrease in value when compared to the other laminates. The fuel-sump water soaked panels mean failure strengths were 25,176 psi and 25,308 psi. The ambient environment exposed panel and the oven control panel mean strengths were 26,129 psi and 27,568 psi respectively. The mean tensile strengths of the two new panels, which were tested prior to the six month test period, were 26,829 psi and 27,039 psi (Figure A-1 and Table A-7).

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this program was to determine if graphite-epoxy composite material properties could be degraded by exposing the laminate to pressurized JP-4 fuel. The study dealt primarily with the tensile testing of fuel and ambient environment exposed laminates and oven dried laminates to determine relative strength values. Also, a test condition was set up to evaluate the effects of fuel tank sump water on the composite properties. The conclusions from this effort were:

1. Composite laminates will not absorb a significant amount of JP-4 fuel, after exposure to JP-4 fuel at a 40 psi pressure for six months.

2. The results of Test No. 1 show no degradation of the laminate strength due possibly to having fiber dominated failures rather than matrix controlled failures. The mean tensile strength of the fuel soaked laminates was actually greater than that of the ambient environment exposed laminates. The short beam shear and flexural strength average results were essentially the same for all laminates.

3a. The test results of Test No. 2 show no significant degradation in the strength of the test laminates. The tensile strength results show that the fuel exposed and ambient environment exposed laminates had the same average strength. The oven control panel had a slightly higher average failure strength than the other specimens although it was still within 2%.

b. The short beam shear test results show the ambient environment exposed laminate had a shear strength higher than the fuel exposed and oven dried laminates. Short beam shear strengths of the fuel exposed and oven dried laminates were essentially the same.

c. The flexural strength of the ambient environment exposed and oven control specimens was approximately 4% greater than the fuel soaked flexural strength values. No conclusions can be made from this test due to the small sample size and the large deviation in failure loads.

4. Test No. 3 data shows that the fuel plus artificial sump water mixture reduces the strength of the composite materials. The fuel-sump water soaked tensile failure loads are consistenly lower than the other laminate failure loads, as shown in Figure 11. The mean failure load of the new material test specimens was 2176 lbs. The mean failure load of the fuel-sump water test specimens was 2060 lbs.

5. This study has shown that there is little or no degradation of composite material properties due to JP-4 fuel. The undamaged composite matrices used in this investigation were very resistant to JP-4 fuel. It is apparent from this study that further investigations are required to determine if fuel sump water has a significantly detrimental effect on composite material properties.

The following recommendations are made to further investigate the compatibility of composite fuel tanks with fuel and sump water:

1. Investigations should be conducted on matrix damaged composite fuel tanks since the resistance of the composites to JP-4 fuel depends largely on undamaged resins.

2. Additional studies should be made to determine if fuel tank sump water significantly reduces composite material properties beyond the normal reduction due to moisture absorption.

APPENDIX

TEST DATA

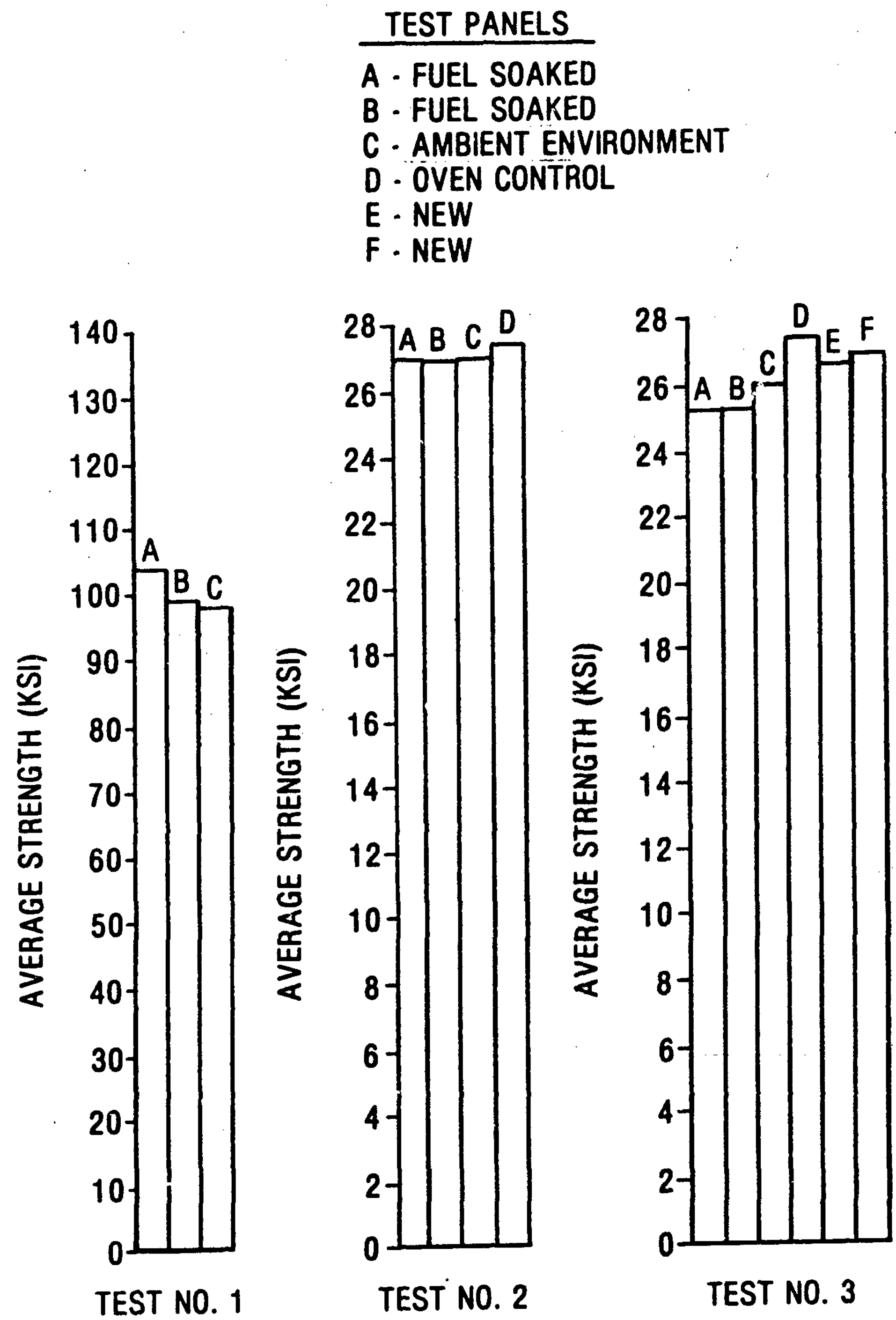

Figure A-1. Tensile Test Results

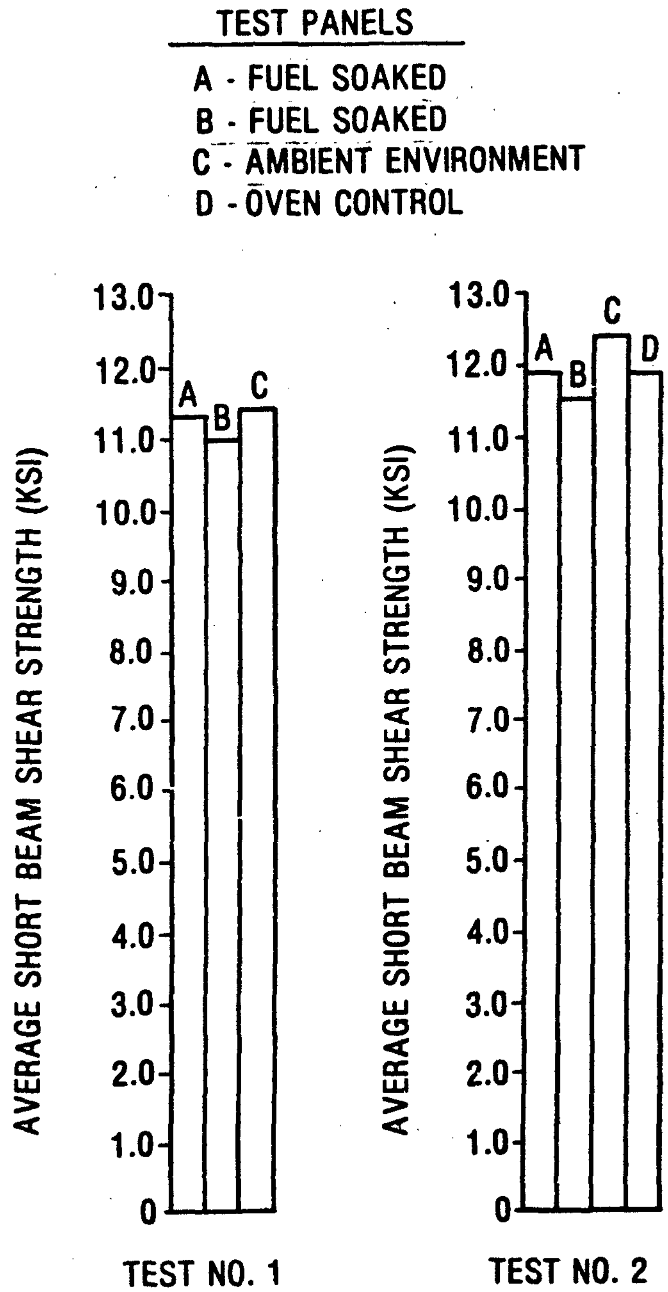

Figure A-2. Short Beam Shear Test Results

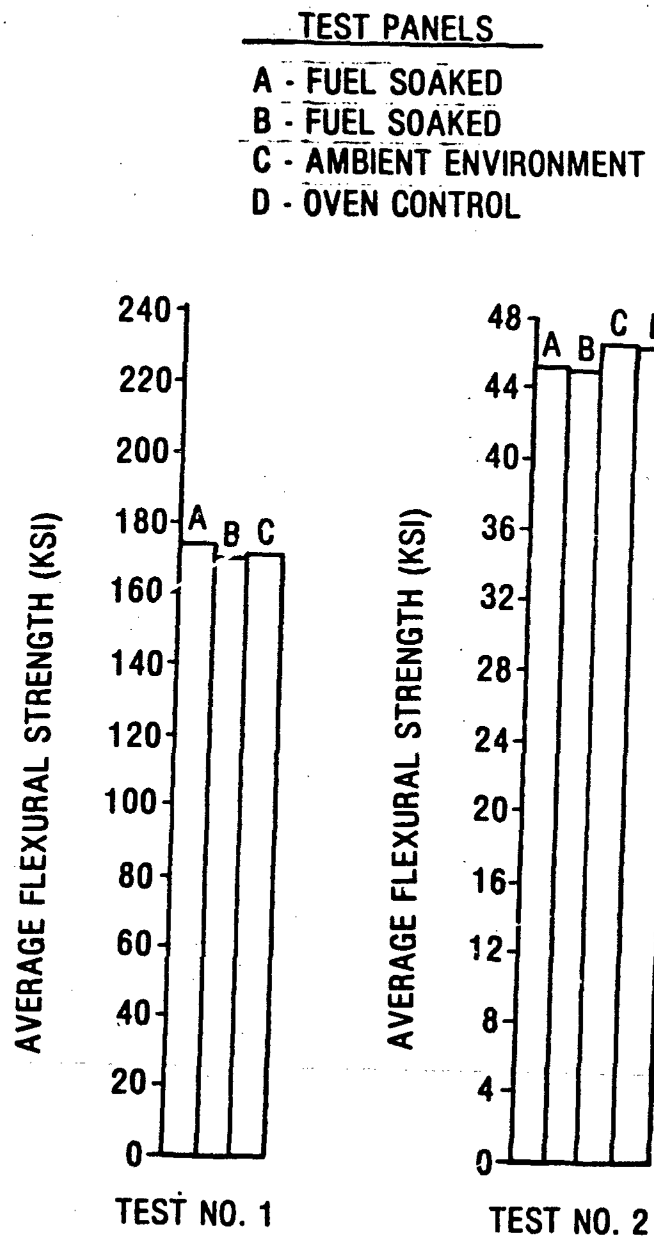

Figure A-3. Flexural Strength Test Results

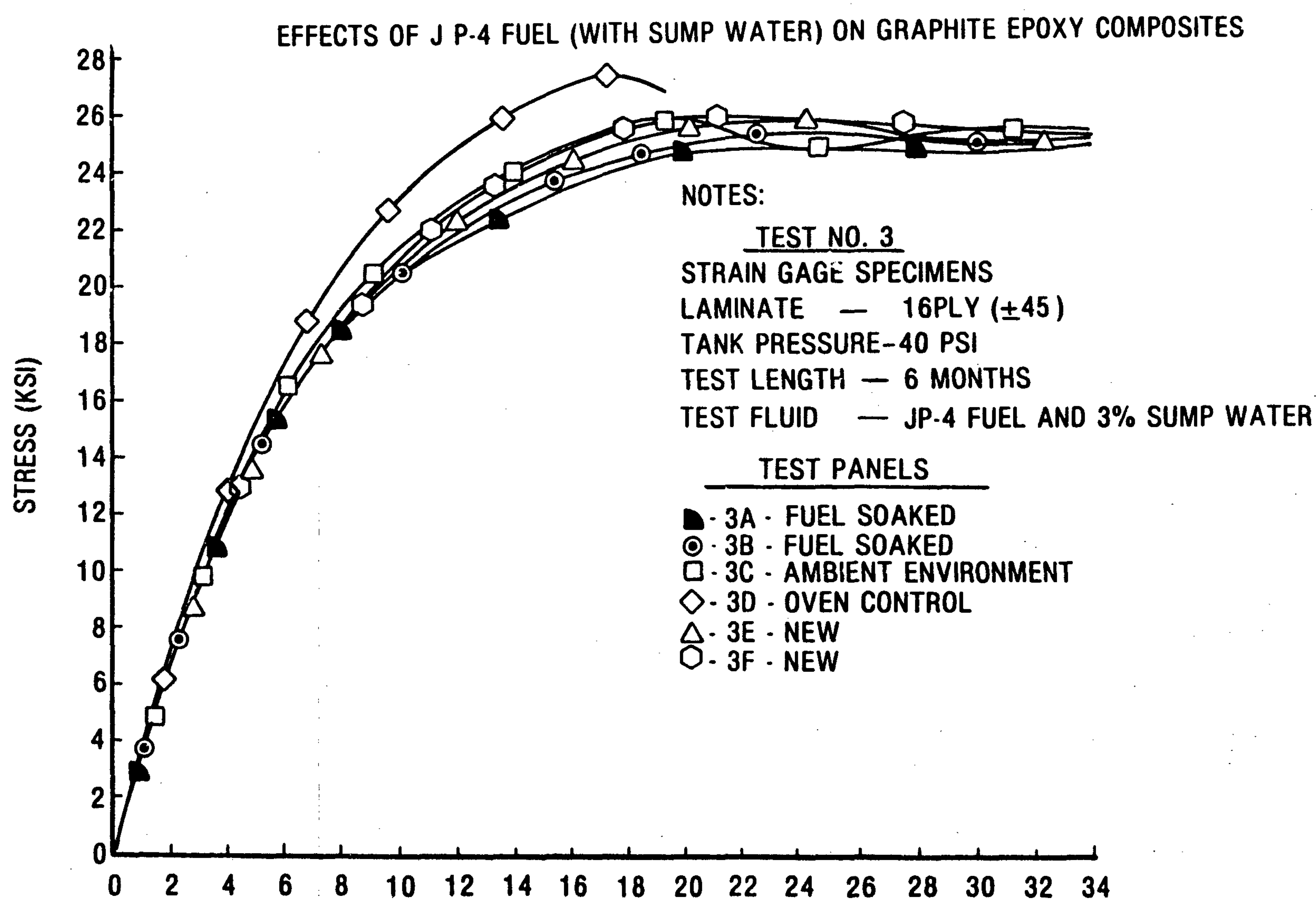

Figure A-4. Stress Versus Axial Strain - Test No. 3

TABLE A-1 TENSILE TEST RESULTS-TEST NO.1

TENSILE SPECIMEN NO.	PANEL 1A (FUEL SOAKED)		PANEL 1B (FUEL SOAKED)		PANEL 1C (AMBIENT ENVIRONMENT)	
	FAILURE LOAD (LB)	STRESS (PSI)	FAILURE LOAD (LB)	STRESS (PSI)	FAILURE LOAD (LB)	STRESS (PSI)
2	6280	99683	5880	93333	5580	88571
3	7105	112778	6400	101587	5100	80952
4	6702	106380	5810	92222	6390	101429
5	6902	109556	7170	113810	6200	98413
6	6804	108000	7040	111746	6325	100397
7	5900	93650	7050	111905	6320	100317
8	6650	105556	5480	86984	6330	100476
9	6670	105873	6000	95238	6310	100159
11	6360	100952	6003	95286	6510	103333
12	6103	96873	5990	95079	6880	109206
13	7002	111143	5850	92857	6910	109683
14	6650	105556	6220	98730	6000	95238
15	6680	106032	5790	91905	5500	87302
16	5780	91746	6710	106508	5802	92095
17	6650	105556	6702	106381	5860	93016
18	6200	98413	5800	92063	6200	98413
20	6150	97619	5601	88905	6330	100476
Mean:	6504	103238	6205	98502	6149	97612
Standard Deviation	383	6085	537	8535	469	7454
Coef. of Varation	5.89	5.89	8.66	8.66	7.63	7.63

Note: Nominal 12 ply Thickness = 0.063 in

TABLE A-2 SHORT BEAM SHEAR TEST RESULTS-TEST NO. 1

SHEAR SPECIMEN NO.	PANEL 1A (FUEL SOAKED)			PANEL 1B (FUEL SOAKED)			PANEL 1C (AMBIENT ENVIRONMENT)		
	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)
1	0.0173	250	10838	0.0174	266	11466	0.0172	244	10640
2	0.0173	292	12659	0.0181	267	11063	0.0174	289	12457
3	0.0172	260	11337	0.0181	235	9738	0.0173	275	11922
4	0.0175	270	11571	0.0177	286	12119	0.0177	294	12458
5	0.0171	242	10614	0.0179	255	10684	0.0177	263	11144
6	0.0169	241	10695	0.0175	251	10757	0.0173	229	9928
Mean:	0.0172	259	11286	0.0177	260	10971	0.0174	266	11425
Stand. Dev.:	0.0002	19.5	770.7	0.0003	17.3	802.5	0.0002	25.5	1031
Coef. of Var.:			6.83			7.31			9.02

TABLE A-3 FLEXURAL STRENGTH TEST RESULTS-TEST NO. 1

FLEXURAL SPECIMEN NO.	PANEL 1A (FUEL SOAKED)				PANEL 1B (FUEL SOAKED)				PANEL 1C (AMBIENT ENVIRONMENT)			
	THICKNESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)	THICKNESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)	THICKNESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)
1	0.067	0.501	236	157404	0.070	0.500	266	162857	0.069	0.499	261	164791
2	0.067	0.504	258	172077	0.070	0.504	272	165209	0.069	0.499	279	176156
3	0.067	0.504	259	171716	0.069	0.501	264	166020	0.069	0.501	263	165391
4	0.069	0.501	254	159731	0.069	0.503	264	165359	0.069	0.505	269	165824
5	0.068	0.501	265	171586	0.070	0.503	285	173449	0.068	0.504	238	153186
6	0.069	0.503	268	167865	0.069	0.500	244	153749	0.069	0.501	266	167277
Mean:			257	166730			266	164441			262	165438
Stand. Dev. :			11.3	6546			13.3	6355			13.6	7334
Coef. of Var. :				3.92				3.86				4.43

TABLE A-4 TENSILE TEST RESULTS-TEST NO. 2

TENSILE SPECIMEN NO.	PANEL 2A (FUEL SOAKED)			PANEL 2B (FUEL SOAKED)			PANEL 2C (AMBIENT ENVIRONMENT)			PANEL 2D (OVEN CONTROL)		
	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)
1	.0869	2390	27503	.0868	2374	27350	.0837	2267	27085	.0868	2381	27431
3	.0862	2360	27378	.0873	2368	27125	.0874	2326	26613	.0877	2387	27218
4	.0871	2345	26923	.0875	2364	27017	.0878	2370	26993	.0879	2417	27497
5	.0864	2315	26794	.0872	2346	26904	.0876	2374	27100	.0878	2420	27563
6	.0886	2388	26953	.0871	2351	26992	.0872	2368	27156	.0876	2409	27500
7	.0890	2373	26663	.0877	2364	26956	.0871	2360	27095	.0878	2432	27699
8	.0882	2377	26950	.0875	2352	26880	.0871	2379	27313	.0893	2438	27301
9	.0873	2358	27010	.0870	2333	26816	.0882	2389	27086	.0882	2425	27494
11	.0873	2328	26667	.0873	2344	26850	.0879	2384	27121	.0877	2439	27811
12	.0873	2335	26747	.0872	2346	26904	.0878	2368	26970	.0877	2435	27765
13	.0875	2325	26571	.0880	2338	26568	.0889	2380	26772	.0888	2397	26993
14	.0870	2354	27057	.0877	2375	27081	.0875	2357	26937	.0892	2410	27018
15	.0874	2342	26796	.0885	2364	26712	.0880	2357	26784	.0879	2416	27486
16	.0868	2364	27235	.0881	2348	26652	.0886	2342	26433	.0882	2430	27551
17	.0868	2329	26832	.0870	2348	26998	.0875	2342	26766	.0875	2420	27657
19	.0862	2338	27123	.0870	2349	27000	.0858	2360	27506	.0868	2397	27615
20	.0855	2325	27193	.0852	2332	27371	.0871	2348	26958	.0887	2355	26550
Mean	.0872	2350	26964	.0873	2353	26944	.0885	2357	26982	.0879	2412	27421
Stand. Dev.	.00083	23.09	259.9	.00071	13.29	212.3	.0035	28.58	256.2	.0007	22.76	322.1
Coef. of Var.			0.964			0.788			0.949			1.17

TABLE A-2 SHORT BEAM SHEAR TEST RESULTS-TEST NO. 2

SHEAR SPECIMEN NO.	PANEL 2A (FUEL SOAKED)			PANEL 2B (FUEL SOAKED)			PANEL 2C (AMBIENT ENVIRONMENT)			PANEL 2D (OVEN CONTROL)		
	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	SHEAR STRENGTH (PSI)
1	.0222	352	11867	.0232	353	11418	.0223	371	12473	.0229	394	12930
2	.0234	352	11274	.0227	368	12171	.0225	361	12053	.0241	350	10837
3	.0226	377	12514	.0227	351	11576	.0218	329	11325	.0233	349	11223
4	.0236	358	11398	.0246	366	11159	.0218	381	13090	.0236	367	11679
5	.0225	364	12137	.0233	366	11798	.0219	361	12360	.0251	382	11422
6	.0226	360	11964	.0234	351	11267	.0217	334	11532	.0234	367	11775
7	.0228	376	12391	.0222	343	11576	.0216	382	13256	.0217	367	12671
8	.0223	353	11872	.0238	352	11105	.0213	390	13696	.0225	373	12449
9	.0230	349	11383	.0228	363	11953	.0216	344	11950	.0226	355	11777
Mean	.0228	360	11867	.0232	357	11558	.0218	361	12415	.0231	367	11868
Stand Dev.	.0004	3.4	148.2	.0007	8.8	363.7	.0004	21.8	800.4	.0010	14.7	683.7
Coef. of Var.			3.74			3.14			6.44			5.76

TABLE A-6 FLEXURAL STRENGTH TEST RESULTS-TEST NO. 2

FLEXURAL SPECIMEN NO.	PANEL 2A (FUEL SOAKED)				PANEL 2B (FUEL SOAKED)			
	THICK-NESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)	THICK-NESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)
1	.0870	.5017	115	45426	.0863	.5004	109	43871
2	.0864	.5023	113	45204	.0863	.5006	111	44658
3	.0863	.5029	112	44855	.0862	.5006	114	45972
Mean	.0866	.5023	113	45161	.0863	.5005	111	44834
Stand Dev.	.0004	.0006	1.5	288	.0001	.0001	1.5	613
Coef. of Var.				.637				2.36

FLEXURAL SPECIMEN NO.	PANEL 2C (AMBIENT ENVIRONMENT)				PANEL 2D (OVEN CONTROL)			
	THICK-NESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)	THICK-NESS (IN)	WIDTH (IN)	LOAD (LB)	FLEXURAL STRENGTH (PSI)
1	.0869	.5006	120	47615	.0873	.5011	115	45169
2	.0881	.5007	120	46317	.0878	.5006	123	47810
3	.0872	.5001	115	45363	.0871	.5004	115	45440
Mean	.0874	.5005	118	46432	.0874	.5007	117	46140
Stand Dev.	.0006	.0003	2.9	1130	.0004	.0004	4.6	1452.8
Coef. of Var.				2.43				3.14

TABLE A-7 TENSILE TEST RESULTS-TEST NO. 3

TENSILE SPECIMEN NO.	PANEL 3A (FUEL/SUMP WATER)			PANEL 3B (FUEL/SUMP WATER)			PANEL 3C (AMBIENT ENVIRONMENT)		
	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)
1	.0822	2080	25304	.0808	2080	25743	.0809	2140	26452
2 *	.0824	2024	24563	.0815	2067	25362	.0808	2117	26200
3	.0817	2050	25092	.0819	2070	25275	.0830	2140	25783
4	.0824	2055	24939	.0832	2080	25000	.0820	2140	26098
5	.0830	2070	24940	.0828	2065	24940	.0801	2140	26717
6	.0817	2075	25398	.0852	2065	24237	.0832	2140	25721
7	.0805	2075	25776	.0801	2050	25593	.0816	2130	26103
8	.0817	2060	25214	.0802	2050	25561	.0813	2150	26445
9	.0809	2050	25340	.0802	2040	25436	.0814	2150	26412
10 *	.0809	2044	25266	.0802	2028	25287	.0828	2115	25543
11	.0811	2055	25339	.0811	2050	25277	.0828	2150	25966
12	.0821	2070	25213	.0808	2050	25371	.0821	2165	26370
13	.0822	2060	25061	.0811	2060	25401	.0819	2145	26190
14	.0818	2070	25306	.0810	2065	25494	.0826	2140	25908
15	.0817	2075	25398	.0823	2065	25091	.0822	2150	26156
16	.0816	2055	25184	.0804	2070	25746	.0809	2150	26576
17	.0822	2050	24939	.0830	2090	25181	.0830	2150	25903
18 *	.0811	2043	25191	.0813	2079	25571	.0828	2117	25568
19	.0819	2040	24908	.0829	2070	24970	.0812	2120	26188
20	.0812	2040	25123	.0812	2080	25616	.0805	2115	26273
Mean	.0817	2057	25176	.0816	2064	25308	.03177	2138	26129
Stand Dev.	.0006	14.9	248	.0013	15.3	349	.0009	14.5	324
Coef. of Var.			0.986			1.38			1.24

* - Strain Gaged Specimens

TABLEA-7(Con't) TENSILE TEST RESULTS-TEST NO. 3

TENSILE SPECIMEN NO.	PANEL 3D (OVEN CONTROL)			PANEL 3E (NEW)			PANEL 3F (NEW)		
	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)	AREA (IN^2)	FAILURE LOAD (LB)	STRESS (PSI)
1	.0825	2220	26909	.0810	2125	26235	.0808	2165	26795
2 *	.0814	2217	27232	.0812	2135	26293	.0809	2112	26106
3	.0810	2200	27160	.0811	2200	27127	.0808	2160	26733
4	.0819	2180	26618	.0817	2205	26989	.0814	2190	26904
5	.0821	2200	26797	.0807	2200	27261	.0800	2160	27000
6	.0809	2190	27071	.0810	2195	27099	.0812	2180	26847
7	.0814	2180	26781	.0807	2220	27509	.0802	2200	27431
8	.0806	2250	27915	.0812	2175	26786	.0811	2195	27065
9	.0804	2240	27861	.0805	2175	27019	.0810	2195	27099
10 *	.0802	2217	27643	.0818	2090	25550	.0800	2120	26500
11	.0800	2230	27875	.0812	2150	26479	.0806	2185	27109
12	.0800	2230	27875	.0800	2165	27163	.0806	2200	27295
13	.0806	2250	27916	.0813	2190	26937	.0802	2200	27431
14	.0804	2250	27985	.0816	2200	26961	.0801	2205	27528
15	.0802	2260	28180	.0816	2195	26900	.0816	2200	26961
16	.0813	2260	27798	.0816	2180	26715	.0808	2205	27290
17	.0811	2250	27743	.0814	2200	27027	.0792	2190	27652
18 *	.0800	2248	28100	.0808	2149	26597	.0797	2119	26587
19	.0803	2250	28020	.0807	2190	27138	.0803	2190	27273
20	.0813	2250	27676	.0808	2165	26795	.0802	2180	27182
Mean	.0809	2228	27568	.0811	2172	26829	.0805	2177	27039
Stand Dev.	.0007	27.0	484	.0004	38.1	437	.0006	31.7	378
Coef. of Var.			1.76			1.63			1.40

* - Strain Gaged Specimens

TABLE A-8 ARTIFICIAL FUEL TANK SUMP WATER (Reference 7)

COMPOSITION	% BY WEIGHT	METAL (PPM)	CHLORIDE (PPM)
$CaCl_2$	0.005	18	32
$CdCl_2$	0.100	490	310
$MgCl_2$	0.005	6	18
$NaCl$	0.010	20	30
$ZnCl_2$	0.001	4.7	5.2
$CrCl_3 \cdot 6H_2O$	0.0001	0.2	0.3
$CuCl_2 \cdot 2H_2O$	0.0001	0.4	0.4
$FeCl_3$	0.0005	1.7	3.3
$MnCl_2 \cdot 4H_2O$	0.0005	1.4	1.8
$NiCl_2 \cdot 6H_2O$	0.0001	0.2	0.3
$PbCl_2$	0.0001	0.7	0.3
		543.3	401.6

Adjust to PH = 4.5 Using HNO_3

REFERENCES

1. I. G. Hedrick, J. B. Whiteside, "Effects of Environment on Advanced Composites Structures" presented at the AIAA Conference on Aircraft Composites, San Diego, CA, March 1977.

2. N. C. W. Judd, et al., "The Effects of Aviation Fluids on Carbon/Epoxy Composite Panels", SAMPLE Journal, May/June 1977.

3. L. G. Kelly, Unpublished paper, "Environmental Effects on Composites", Materials Laboratory, WPAFB, OH, 1970.

4. C. L. Hendricks, "A Study of the Effects of Long-Term Exposure to Fuels and Fluids on the Behavior of Advanced Composite Materials", NASA Report D-6-41185-6, Sept 1977.

5. C. D. Shirrell, "Diffusion of Water Vapor in Graphite/Epoxy Composites", SESA Conference, Philadelphia, Pa, Oct 1977.

6. MIL-Handbook-5-C, 15 Sept 1976.

7. C. W. Cooper, et al., "Elastomers for Fuel Systems Containing Microorganism-Control'' j Additives" AFML TDK-63-4195, Part II, Jan 1965.

8. R. S. Sandhu, I. S. Rai, "Finite Element Analysis of Anisotropic Plates Using Q-19 Element", AFFDL-TR-74-12C, Part II, Oct 1974.

9. D. L. Reed, SQ5-Point Stress Laminate Analysis, FZM-5494, AF Contract F33615-69-C-1494, General Dynamics, Fort Worth Division, April 1970.